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Status Report

ENVIRONMENTAL, SAFETY AND HEALTH ASSESSMENT OF FY93 TASKS IN PROJECT BE12, IMAGING TECHNIQUES APPLIED TO THE STUDY OF FLUIDS IN POROUS MEDIA

By

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FOREWORD

This Status Report, prepared in fulfillment of Task 1 of the Annual Research Plan, describes the environmental, safety, and health (ES&H) concerns related to Project BE12 and the actions necessary to address and mitigate those concerns. The objectives of Task 1 are to review the procedures, equipment, and working conditions to ensure compliance with all federal, state, and local regulations, and to ensure that all activities are planned and conducted in a safe and environmentally sound manner. Potential areas of concern in Project BE12 include the use of flammable and potentially toxic solvents and fluids, use of X-rays in the CT scanner, use of mercury in the injection porosimeter, use of cryogens and high magnetic fields associated with the NMR spectrometer, and the use of laboratory mechanical and electronic equipment. Each of these areas is addressed with a combination of training, standard procedures, and personal protective equipment.

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OBJECTIVE

Department of Energy requirements emphasize the need to place high priorities on environmental, safety, and health issues. The objectives of Task 1 of Project BE12 are to review the experimental program for this DOE-sponsored project and to evaluate procedures, equipment, and working conditions to ensure that environmental, health, and safety considerations are satisfied.

INTRODUCTION

Project BE12 is a laboratory-scale project. The volumes of wastes generated are less than 50 gallons per year. The total weight of rock specimens used for project tasks is less than 25 pounds.

Project BE12 efforts will be directed towards several areas: (1) Investigation of using single- and multi-energy X-ray scans for rapid characterization of cores. (2) Application of imaging technology to derive scale-up procedures for permeability and relative permeability in large heterogeneous samples. (3) Investigation of the applicability of nuclear magnetic resonance (NMR) spectroscopy and microscopy to the study of rock/fluid interactions affecting wettability. (4) Develop an appropriate technology transfer activity such as a rock/fluid imaging workshop or short course. The installation of a second CT scanner may be completed and used to search for correlations between X-ray beam energy/attenuations and rock porosity and mineral composition. A variety of porous rocks will be studied. The petrographic and petrologic properties of the rocks will be well characterized using X-ray diffraction, thin section petrographic analysis, and mercury injection porosimetry. The fluid systems (brine, gas, or hydrocarbon liquid) will be designed to provide the appropriate rock/fluid contrast or visibility for the various imaging techniques (CT and MRI). Simulations will be used to scale up permeability and relative permeability values from small core plugs to large cores or slabs. Project tasks are given in appendix A.

Project tasks and safety considerations include the following groups of measurements:

A. Task 2 - X-ray CT scanning and mercury-injection porosimetry of rock samples.
   1. Possible exposure of operators to X-radiation during CT scanning at beam energies between 77 and 140 kV.
   2. Mercury will be used in the injection porosimetry measurements.
   3. Contrast fluids (brine containing sodium iodide or xenon) will be used during some CT scans.
   4. Rock cleaning solvents may be used which have low flash points (methanol, isopropyl alcohol, pentane.)

B. Task 3 - Core flood experiments and rock characterization.
   1. Large rock samples will be encapsulated using epoxy resins.
   2. Low fluid pressures below 50 psig will be used at ambient

temperatures for core flooding experiments.

3. Possible exposure of operators to X-radiation during CT scanning at beam energies between 77 and 140 kV.
4. Mercury will be used in the injection porosimetry measurements. 10 to 30 samples (1 inch long .5 in.) are expected to be analyzed by mercury injection. After analysis each rock sample will contain approximately 0.55 cm^3 of mercury.
5. The hydrocarbon oil has a flash point of 105° F and an ignition temperature of approximately 410° F.
6. Contrast fluids (brine containing sodium iodide or xenon) will be used during some CT scans.
7. Rock cleaning solvents may be used which have low flash points (methanol, isopropyl alcohol, pentane.)

C. Task 4 - NMR spectroscopy and MRI imaging of rock/fluid samples.

1. The superconducting magnet in the NMR spectrometer generates a strong magnetic field that extends beyond the magnet cryostat.
2. Super cold cryogens (liquid nitrogen - BP 77 K and liquid helium - BP 4 K) are used to maintain the superconducting magnetic field.
3. Some NMR spectrometry will use deuterated chloroform as a solvent for organic samples.
4. NMR relaxation reagents ($MnCl_2$) will be used in the fluid phases to shorten measurement times.
5. Short strong radio frequency (RF) pulses (<50 μsec, < 400 watts) are used to generate the NMR signals.
6. The hydrocarbon oil has a flash point of 105° F and an ignition temperature of approximately 410 F.
7. Rock cleaning solvents may be used which have low flash points (methanol, isopropyl alcohol, pentane.)

POTENTIAL HAZARDS

The principle hazards associated with this work include the following:

A. Use of flammable solvents and fluids.
B. Use of various chemicals with different health and safety requirements for cleaning rock and for preparing the test fluids.
C. Use of X-ray CT equipment for rock characterization.
D. Use of mercury injection porosimeter to measure porosity.
E. Handling of cryogens for routine maintenance of NMR equipment.
F. Use of sophisticated laboratory mechanical and electronic equipment.
G. High magnetic field in NMR lab could be hazardous to people with heart pacemakers.

CORRECTIVE ACTIONS TAKEN OR PROPOSED

The following actions will be taken to limit the potential for an accident occurrence:

A. Solvents will be used in well ventilated environments and preferably within vent hoods. Personal contact with solvents will be minimized. Handling of chemicals will be performed using appropriate protective equipment.
B. NIPER ES&H policies will be obeyed.

C. All pressure vessels, including cryogen transfer dewars, will be equipped with pressure relief safety valves to prevent pressure buildup beyond safe limits.

D. X-ray radiation badges for both body and hands will be worn by staff members to monitor exposures on a monthly basis.

E. Appropriate safety equipment and procedures will be followed in handling the cryogens to recharge the NMR cryostat to maintain the magnetic field.

F. MSD sheets will be consulted as necessary by the project staff to determine safe methods for handling and storing solvents and other chemicals.

G. Solvent and chemical wastes generation will be minimal. All wastes will be disposed of in approved containers according to NIPER ES&H policy.

H. Monthly ES&H inspections will be conducted by NIPER staff ordinarily not associated with the project.

I. Common sense and professional skills will be used to avoid hazardous situations. Project personnel have done similar work for Government and Industry clients for years without mishaps and are familiar with the various ES&H policies that impact this work.

J. Calculate potential X-ray dosage to the public to ensure non-project staff are protected.

K. Ensure all entries to the CT room are secured and closed during X-ray use to prevent accidental exposure.

L. Due to the low level of possible X-ray exposure, tag out will be adequate to be used on the X-ray CT console activating switch to prevent accidental X-ray exposure.

M. Mercury saturated rock samples will be saved in sealed polyethylene bags and when a sufficient quantity is accumulated, will be disposed as hezardous waste. The personnel preforming the mercury injection experiments will carry personal monitoring devices and will under go appropriate physical exam monitoring merucry blood levels. The mercury injection porosimeter will be placed in properly ventilated enclosure.

APPENDIX A—PROJECT ANNUAL PLAN

SCOPE OF WORK

The imaging techniques developed in BE12 will be used to support other DOE sponsored projects: Reservoir Characterization (BE1), Improved Microbial Flooding (BE3), Improved Surfactant Flooding (BE4A), Improved Mobility Control Methods (BE4C), Mobility Control Profile Modification and Sweep Improvement in Gas Flooding (BE5B), Three-Phase Relative Permeability (BE9), Thermal Processes for Light Oil Recovery (BE11A), and Alkaline-Surfactant-Polymer field projects (SGP41). Researchers will actively participate in support of the field work (heterogeneity description) necessary for selecting fields for subsequent EOR projects in priority reservoir classes. The objectives of these experiments are: (1) to improve the reliability of core measurement data used in oil recovery simulations aiding the identification of high priority reservoirs; (2) to quantify and to observe directly and rapidly the various flow regimes and mobilization of trapped oil in EOR processes and improved waterflooding, to aid in the selection of optimal recovery process for a priority reservoir class; and (3) to develop fundamental understanding needed to identify novel techniques for recovering immobile oil. Oil trapping and removal under various flow regimes will be quantified for reservoir rocks from high priority reservoir field projects (near- to mid-term). The application of image analysis techniques to the investigation of enhanced oil recovery methods will require specific adaptations both in core flooding equipment automation and data processing software to increase efficiency. These improvements will increase industrial utilization of these technologies for near-term optimization of oil recovery processes.

Scaling procedures will be studied both experimentally and through simulations using reservoir samples representative of fields from a high priority reservoir class. The CT scanner will be used to observe porosity, permeability and fluid distributions in samples with sizes ranging from 1 to 4 in. across and 2 in. to 1 ft long to characterize the various heterogeneity scales. Pore geometries and fluid distribution in locations where oil trapping takes place will be studied by means of computer image analysis of thin sections and high resolution NMRI. Using these techniques, correlations and scaling procedures will be derived for the laboratory corefloods measured.

NMR spectroscopy and the NMR microscopy techniques developed at NIPER will be used to investigate the relationship between wettability and fluid distributions in the pore space in both synthetic and natural porous media. The results of this research will contribute to improving the interpretation of special core analyses data and advance the accuracy of the predictions of oil recovery by simulations.

Technology transfer will be accomplished by the preparation of DOE reports, journal articles, presentations for symposia, and through an industry consortium or advisory panel.

Task 1. Environmental, Safety and Health. (Start date: October 1992. Completion date: November 1992.) (Short-Term).

Evaluate the environmental, safety and health aspects of the procedures, activities and equipment required to conduct the tasks planned for FY93. Design safe procedures and equipment setups if conflicts with NIPER's ES&H policies are identified. After review by the IITRI ES&H manager, a status report on the assessment results will be submitted to the BPO for approval.

Task 2. Investigation of using single- and multi-energy scans for rapid characterization of cores. (Start date: November 1992. Completion date: August 1993.) (Near-Term).

Complete installation of second CT scanner to be used to search for correlations of X-ray beam attenuations and images at energies between 77 kV and 140 kV and mineral composition and porosity of rock samples. The mineral composition will be determined by X-ray diffraction and petrographic analysis of thin sections while the porosity will be determined by X-ray beam attenuations of the sample before and after saturation with a contrast fluid (brine or Xenon). The pore characterization will be performed by using thin section image analysis and mercury injection porosimetry. The goal is to provide a procedure for quick scanning of whole cores to generate and porosity profiles. These profiles can be used to help select representative core plug samples for measurements of relative permeabilities, capillary pressures, etc.

Task 3. Apply imaging technology to derive scale-up procedures for permeability and relative permeability in large heterogeneous samples. (Start date: October 1992. Completion date: August 1993.) (Mid- to Long-Term)

Perform coreflood experiments in large heterogeneous rock samples representative of Class 1 reservoirs. The rock will be characterized using minipermeameter, CT, mercury injection, scanning electron microscopy (SEM), and computer-assisted petrographic image analysis. Simulations will be used to scale up permeability and relative permeability values from small core plugs characterizing specific rock types to the large core or slab containing the various rock types.

Task 4. Investigate the applicability of NMR spectroscopy and NMRI microscopy to study of rock fluid interactions affecting wettability. (Start date: October 1992. Completion date: August 1993.) (Mid- to Long-Term)

Measurements of relaxation times and imaging with various pulse timing sequences available in the present NMRI microscopy instrument will be used to characterize pore geometry, pore connectivity, fluid distribution at pore level and the fluid-rock surface interaction for rocks with various wettabilities.

Task 5. Technology Transfer. (Start date: October 1992. Completion date: August 1993.) (Near-Term).

Determine the format of a technology transfer activity. A Rock - Fluid imaging workshop or short course will be considered, preferably in conjunction with a professional meeting. Effort will continue toward establishing an industry consortium to help plan, review, and participate in the research through the Work-For-Others category of the Cooperative Agreement and to provide for effective technology transfer.

Task 6. Final Report Preparation. (Start date: March 1993. Completion date: August 1993.) (Near-Term).

A summary report highlighting the accomplishments at NIPER and the state of the art technology in the application if imaging technology to rock and rock-fluid characterization will be written. This report will also propose future directions of imaging technology applications to fluids in porous media and will be incorporated as a chapter in the NIPER Final Technical Report. It will include:

(1) Use of the computer assisted image analyses of thin sections for porosity and permeability determination;

(2) Use of the X-ray CT scanning for core characterization and fluid saturation measurements;

(3) Use of NMR microscopy for pore level study of rock-fluid interaction;

(4) Scale-up from core plug to whole-core to well-bore scale based on X-ray and NMR imaging, and with simulation results. Application of scale up methodology to interwell scale.

BENEFITS AND TECHNOLOGY TRANSFER

- Improved reservoir rock characterization and representative core plug selection based on nondestructive core measurements.

- Improved evaluation of advanced oil recovery methods by direct observation of oil, brine, and gas at scales from pore to whole core.

- Improved understanding of the effect of rock heterogeneities on oil trapping. Improvement in scaling up procedures from laboratory measurements on core plugs to interwell spacing.

- Improved technology transfer mechanism.

- Integrated research with other Base Program, SGP and Work-For-Others projects.

DELIVERABLES

Aug 93 A chapter in the NIPER Final Technical Report summarizing the accomplishments in the application in imaging to rock and rock-fluid characterization.

Sep 93 Status report describing the application of NMR spectroscopy and microscopy to the study of wettability.

APPENDIX B—PROJECT PLAN ES&H CHECKLIST

IDENTIFICATION OF TRAINING NEEDS

- [ ] Employee Emergency Plans/Fire Prevention
- [ ] Noise
- [ ] Flammable/Combustible Liquids
- [ ] Hazardous Waste Operations and Emergency Response (HAZWOPER)
- [ ] Medical and First Aid
- [x] Lockout/Tagout
- [ ] Occupational Exposure to Hazardous Chemicals in the Laboratories
- [ ] Bloodborne Pathogens
- [x] Other (Reenergizing NMR cryostat)
- [ ] Ventilation
- [x] Radiation
- [ ] Storage and Handling of Liquefied Petroleum Gases
- [ ] Respiratory Protection
- [ ] PPE
- [ ] Toxic and Hazardous Substances
- [ ] Hazard Communication
- [ ] Portable Fire Extinguishers

HAZARDS IN THE WORKPLACE

- [x] OSHA Controlled Chemicals:
  - ○ Air contaminant PELs/TLVs
  - ○ Asbestos
  - ○ Coal Tar Pitch Volatiles
  - ○ 4-Nitrobiphenyl
  - ○ alpha-Naphthylamine
  - ○ Methyl Chloromethyl Ether
  - ○ beta-Naphthylamine
  - ○ Benzidine
  - ○ 4-Aminodiphenyl
  - ○ Ethyleneimine
  - ○ beta-Propiolactone
  - ○ 2-Acetylaminofluorene
  - ○ 4-Dimethylaminoazobenzene
  - ○ N-Nitrosodimethylamine
  - ○ Vinyl Chloride
  - ○ Inorganic Arsenic
  - ○ Lead
  - ✓ Benzene
  - ○ Coke Oven Emissions
  - ○ Cotton Dust
  - ○ 1,2,-Dibromo-3-Chloropropane
  - ○ Arylonitrile
  - ○ Ethylene Oxide
  - ✓ Formaldehyde
- [x] Flammable/Combustible Liquids
- [ ] Identification of, Handling and Storage of Hazardous Materials
- [x] Handling Compressed Gas Cylinders
- [x] Handling Cryogenic Materials
- [ ] Control of Radioactive Hazards
- [ ] Carcinogen Control Plan
- [ ] Handling Fine Dust
- [ ] Control of Radioactive Materials
- [ ] Bloodborne Pathogens
- [ ] Equipment Grounding

PROJECT PLAN ES&H CHECKLIST

HAZARDS IN THE WORKPLACE (Continued)

- [x] Glassware Cleaning, Handling
- [ ] Noise
- [x] Laboratory Systems Under Pressure/Vacuum
- [x] Protection from Magnetic Fields
- [ ] Lockout/Tagout
- [x] Ergonomics
- [ ] Safe Use of Laboratory Ovens
- [ ] Signs, Labels, and Identifiers Required
- [x] Protection From Electromagnetic Radiation
- [ ] Confined Space Entry
- [ ] High Temperature/Low Temperature

SPECIAL PROJECT SAFETY REQUIREMENTS

- [x] Emergency Shutdown Procedures
- [ ] Construction Safety & Health
- [ ] Additional ES&H Personal Protective Equipment Requirements
- [x] Additional ES&H Safety Systems/Devices
- [ ] Transportation of Hazardous Materials
- [ ] Planning and Preparedness for Operational Emergencies
- [x] Unattended Operations
- [x] Working Alone Policy
- [ ] Limitations for Working Continuous or Extended Hours
- [ ] Job Hazard Analysis for Operation of Concern
- [ ] Field Project Requirements
- [x] Record Management
- [ ] Additional Fire Protection Requirements
- [ ] Motor Vehicle Safety
- [ ] Respiratory Protection, Ear Protection, Etc.
- [ ] Ventilation Requirements
- [x] Identification of Necessary Safety Interlock Systems
- [ ] Additional Inspections
- [ ] Medical Examinations for Job functions
- [ ] Industrial Hygiene Exposure Monitoring and Surveying
- [ ] Safety Review Committee Requirements
- [x] Safety Audits Necessary by Outside Consultants
- [ ] Document Control Procedures
- [x] General Instrumentation Maintenance and Calibration

PROJECT PLAN ES&H CHECKLIST

SPECIAL PROJECT SAFETY REQUIREMENTS (Continued)

- ☑ Development of Equipment Standard Operation Procedures
- ☐ Sample Chain of Custody

ENVIRONMENTAL COMPLIANCE

RCRA

- ☑ Hazardous Waste - Types & Quantities
- ☑ Waste Minimization
- ☐ Disposal Cost

Aboveground Storage Tanks

- ☐ Bulk Storage Requirements
- ☐ Employee Training
- ☐ Permits

Community Right to Know

- ☐ Extremely Hazardous Substances List - Types & Quantities
- ☐ Employee Training and Emergency Response

Clean Water Act

- ☐ Industrial Waste Discharge
- ☐ Permits
- ☐ Stormwater Runoff

Toxic Substances and Control Act

- ☐ PCB Usage and Storage

Clean Air Act

- ☐ Air Emissions Inventory
- ☐ Permits
- ☐ Air Toxics List
- ☐ Air Monitoring

NEPA

- ☐ Required Effort and Potential Environmental Consequences

Other

- ☐ Spill Response
- ☐ Field Project Requirements
- ☐ Pollution Prevention Methods
- ☐ Environmental Review Committee Requirements
- ☐ Spill Containment - Berms, Etc.
- ☐ Environment Audits Needed: Frequency/Method
- ☐ Other Environmental Compliance Issues